01-07-02

A

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	P01,0540
First Named Inventor or Application Identifier	
Daniel W. Youngner, et al	
Express Mail Label No:	# EL843743104US

ADDRESS TO: **Assistant Commissioner for Patents**
Box Patent Application
Washington, DC 20231

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. X Specification [Total Pages 8]
2. X Drawing(s) (35USC 113) [Total Pages 3]
3. X Declaration and Power of Attorney [Total Pages 3]

a. X Unexecuted copy

b. __ Copy from prior application (37CFR 1.63(d)) *(for continuation/divisional with Box 14 completed)*

[Note Box 4 Below]

i. __ DELETION OF INVENTOR(S)
Signed statement attached deleting Inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).

4. __ Incorporation By Reference (usable if Box 3b is checked) The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 3b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

ACCOMPANYING APPLICATION PARTS

5. __ Assignment Papers (cover sheet & documentation) ________
6. X Letter under 37 CFR 1.41(c).
7. __ English Translation Document *(if applicable)*
8. __ Information Disclosure Statement (IDS)/PTO-1449 __ Copies of IDS Citations
9. __ Preliminary Amendment
10. X Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
11. __ Small Entity Status (37 CFR 1.27)
12. __ Certified Copy of Priority Document(s)
13. __ Other:________

14. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information:*

__ Continuation __ Divisional __ Continuation-in-part (CIP) __ of prior application No:____/________

CLAIMS AS FILED

	(1) FOR		(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) BASIC FEE $740.00
	TOTAL CLAIMS	20	8			
	INDEPENDENT CLAIMS	3	3			
			ANY MULTIPLE DEPENDENT CLAIMS? ()YES (X) NO			
					TOTAL FILING FEE ->	$740.00

X The Commissioner is hereby authorized to charge any additional fees which may be required in connection with this application, or credit any overpayment to ACCOUNT NO. 501-519. A duplicate copy of this sheet is enclosed.

X A check in the amount of $ 740.00 to cover the filing fee is enclosed.

15. CORRESPONDENCE ADDRESS
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SIGNATURE:
TJ:LW

DATE: December 21, 2001

U-11

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Dublin

December 21, 2001

Assistant Commissioner for Patents
Washington, D.C. 20231

Re: Patent application for Daniel W. Youngner et al., entitled: "OPTICAL PRESSURE SENSOR", Our File No. P01,0540

SIR:

Under the provisions of 37 CFR 1.41 (c), I am filing the attached patent application on behalf of Daniel W. Youngner and Son Thai Lu an unexecuted Declaration being submitted herewith, and request that the application papers be assigned a serial number and filing date pursuant to the provisions of 1.53(b) and 1.53(d).

Respectfully submitted,

Melvin A. Robinson (Reg. No. 31,870)

MAR/edr
Enclosures

CERTIFICATE OF MAILING BY EXPRESS MAIL

Express Mail Mailing Label Number EL 843743104 US

Date of Deposit: December 21, 2001

I hereby certify that this correspondence is being deposited with the United States Postal "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to:

Box Patent Application
Assistant Commissioner for Patents
Washington DC 20231

Case Number: P01,0540

Applicant(s): Daniel W. Youngner, et al.

Title: OPTICAL PRESSURE SENSOR

____
Signature of person mailing documents and fees

SPECIFICATION

TITLE
"OPTICAL PRESSURE SENSOR"

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to a pressure sensor, and in particular to a resonant microbeam pressure sensor having a polysilicon microbeam resonator attached to a portion of the sensor diaphragm and a resonator beam and having an optical fiber directing a light beam to the resonator beam to read the resonance mode optically.

Description of the Related Art

A pressure sensor is disclosed in U.S. Patent No. 5,808,210 in which a micromechnical sensor has a polysilicon beam that is an integral part of the diaphragm. The resonant frequency of the beam is a direct result of the pressure applied to the external surface of the diaphragm. Fabrication of this resonant microbeam sensor requires no backside wafer processing, and involves a process and layout independent of wafer thickness for high yield and robustness. Both the diaphragm and the resonant beam are formed from polysilicon. The sensor may have more than one resonant beam. The sensor beam or beams may be driven and sensed by electrical or optical mechanisms. For stress isolation, the sensor may be situated on a cantilevered single crystal silicon paddle. The sensor may be recessed on the isolating die for non-interfering interfacing with optical or electrical devices. The sensor die may be circular for ease in mounting with fiber optic components. The contents of the U.S. Patent

No. 5,808,210 are incorporated herein by reference.

Figure 2 of the present application sets forth an example of an earlier embodiment of a resonant beam pressure sensor. The Figure 2 shows a thin film resonant microbeam absolute pressure sensor 10 in which a beam 12 is held by posts 13 inside a shell 14. The shell 14 is provided on a substrate wafer 16 with a vacuum, or at least a partial vacuum, inside the shell 14. The substrate 16 has a photodiode, or p-n junction, 18 formed on a top surface thereof within the shell 14. A Fabry-Pérot resonant cavity is formed within the shell 14, including a first portion between the beam 12 and the inside of the top of the shell 14 and a second portion of the cavity between the resonant beam 12 and the top of the substrate 16. An optical fiber 20 which is positioned above the shell 14 at the front side of the sensor directs light 22 onto the beam 12 where it encounters the resonant cavity and resonates at a frequency. The resonating beam 12 reflects light back into the optical fiber 20 which transmits the modulated light beam to a light sensor. Changes in pressure result in corresponding changes in the resonant frequency of the beam, so that the pressure is sensed. This device is termed a shell coupled pressure sensor.

In the pressure sensor shown in Figure 2, the light beam from the optical fiber 20 is transmitted through the medium to be sensed, so that the medium under pressure must be transparent for the device to work properly. If the medium is not transparent, some or all of the light leaving the optical fiber 20 is scattered or absorbed before it can bounce off of the beam and re-enter the fiber. This results in degraded performance of the sensor, or even to the point of the sensor being unable to obtain a pressure reading at all.

A further problem is that of packaging the optical fiber 20 with the pressure sensor 10.

The packaging must hold the fiber 20 close to the resonant beam 12 to get a good optical coupling; yet the spacing must be sufficient that the medium to be sensed has access to the shell 14 of the pressure sensor 10.

In **Figure 3**, the fiber 20 and sensor shell 14 are set at a fixed distance from one another by spacers 22. Openings 24 in the spacers 22 permit the medium to be sensed to access the sensor chamber 26 while maintaining the spacing of the optical fiber 20 from the resonant beam 12. This arrangement addresses the issue of positioning of the fiber and sensor, but presents considerable difficulties in micromachining. Further, the medium to be sensed may become trapped in the sensor space 26 and can foul the optical window at the end of the fiber 20. Any dirt or foreign matter in the medium to be sensed may accumulate on the optical elements of the sensor and fiber and result in deterioration in performance and eventually to complete loss of function.

SUMMARY OF THE INVENTION

The present invention provides a pressure sensor which is resistant to contamination and which operates even in non-transparent media. The present pressure sensor includes a substrate on which is mounted a shell forming vacuum resonant cavity within which is supported a resonant beam. A p-n junction is formed on the top surface of the substrate below the resonant beam. An optical fiber carrying a light beam is in an opening in the underside of the substrate and is positioned to direct the light beam through the substrate toward the resonant beam. A Fabry-Pérot cavity is formed within the shell to impose a frequency on the light beam as it is reflected back into the optical fiber. The sensor is thus

able to provide a frequency output that is a direct measure of the pressure applied to the top surface of the shell. A thin film resonant microbeam absolute pressure sensor results.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross sectional view of a pressure sensor according to the principles of the present invention;

Figure 2 is a cross sectional view of a pressure sensor of an earlier embodiment; and

Figure 3 is a cross sectional view of a pressure sensor of the earlier embodiment showing spacers between the optical fiber and the sensor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides an improvement on the earlier embodiments of the thin film resonant microbeam pressure sensors. In particular, a pressure sensor 30 is provided having a resonant beam 32 held by posts 34 in a shell 36. The shell 36 is mounted on a substrate 38 in the top surface of which is provided a photodiode or p-n junction 40. The interior of the shell 36 is evacuated to provide at least a partial vacuum. A Fabry-Pérot optical resonant cavity 42 is formed in the shell 36 including a first portion between the beam 32 and the inside top surface of the shell 36 and a second portion between the underside of the beam 32 and the top surface of the substrate 38. The beam 32 may be partially transparent to permit light to move between the two portions of the optical cavity, or they may be opaque in which case only the lower Fabry-Perot cavity is optically active. The shell 36 and beam 32 are preferably of polysilicon and constitute a microstructure.

An optical fiber 44 is provided in an opening 46 in the underside of the substrate 38. The optical fiber 44 is mounted to direct the light beam from the fiber 44 toward the resonant beam 32. The opening 46 in the underside of the substrate 38 permits the fiber 44 to be positioned close enough to the beam 32 to permit the sensing of the light reflected by the beam 32.

To form the opening 46 in the substrate 38, a silicon on insulator (SOI) wafer is provided having a layer of silicon 48 of about 10 microns formed over a layer of silicon dioxide (SiO_2) 50 of about 1 micron in thickness. The silicon substrate 38 is generally several hundred microns thick. The opening 46 is formed by first photo-patterning a circular hole on the back side of the substrate wafer 38 and then etching the substrate material. The circular hole is preferably slightly larger than the diameter of the optical fiber 44. The etching process stops at or in the silicon dioxide layer 50, leaving the thin silicon layer 48 at the top surface of the substrate 38 at the hole. The selectivity of the etchant for silicon to silicon dioxide is about 300:1, so the etch process is relatively easy to stop at the silicon dioxide layer.

The etching step may be performed before the formation of the sensor structure on the substrate, during the formation of the sensor structure on the substrate, or after the formation of the sensor structure on the substrate.

A hole 46 is etched all the way up to the silicon dioxide layer 50 and the optical fiber 44 is positioned in the hole. Since the silicon layer 48 and the silicon dioxide layer 50 are both transparent to infra-red light, an infra-red light source 52 is used so that the light from the fiber passes through the silicon 48 and silicon dioxide 50 layers and reaches the

photodiode 40 and the beam 32 and shell structure 36.

In operation, the infra-red light from the optical fiber 44 travels through the silicon dioxide and silicon layers 50 and 48 and into the cavity 42 within the shell 36. The light is partially reflected by the surfaces of the beam 32, the surface of shell 36 and the surface of the photodiode or p-n junction 40. The optical cavity 42 provides multiple optical paths involving the top of the photodiode 40, the resonator beam 32 and the inside surface of the shell 36. The various optical paths operate as a set of Fabry-Pérot cavities. The various beams of light that travel along the various optical paths will either constructively interfere with one another or destructively interfere with one another when they arrive at the photodiode 40. The intensity of light arriving at the photodiode therefore changes as the spacing between the resonator elements changes.

Light energy striking the p-n junction 40 at the surface of the substrate 38 results in a charge accumulation in the p-n junction 40. The charge accumulation draws the resonator beam 32 toward the p-n junction 40 through electrostatic attraction. If the light energy striking the p-n junction 40 is reduced, the beam relaxes back away from the junction. If the light energy striking the p-n junction 40 is increased again, the beam is attracted to the junction again. The movement of the beam 32 continues in a cyclic manner to create a physical resonating movement, or vibration, of the beam. The light energy striking the p-n junction may be increased and decreased either by modulating the light energy at its source (e.g. modulating the intensity of the laser), or by making the structure self-resonant as taught in U. S. Patent No.5,559,358.

The physically resonating beam 32 in the optical Fabry-Perot cavities modulates the light that is reflected back into the optical fiber with changing frequencies. The modulated light is sensed by the sensor 52 to define a pressure state of the pressure sensor. When the sensor element 30 is subjected to pressure changes, the tension on the beam changes which changes the frequency of vibration of the beam and a corresponding change in the modulation of the light returned into the fiber 44. Therefore, pressure changes are sensed in the present pressure sensor 30.

It is noted that no electrical connections are present to the photodiode or p-n junction 40. The junction is present to accumulate charges.

The present invention effectively senses pressure even though the light of the optical fiber 44 passing through the p-n junction 40 and the substrate 38. In particular, with the present invention it is still possible to sense the modulation of the light and the variations therein even though the p-n junction 40 is directly illuminated by the light of the optical fiber 44 passing therethrough. This is because the light that passes through the Fabry-Perot cavity after illuminating the photodiode interferes with the light that directly illuminates the photodiode.

By positioning the optical fiber 44 in the hole 46, it is possible to locate the fiber 44 about 10 microns from the resonant beam 32, resulting in a good optical coupling between the beam 32 and the fiber 44.

The present invention permits the sensing of pressure using a resonant beam sensor without regard to the optical properties of the medium to be sensed. The medium may be

dirty or even opaque. Furthermore, the medium does not result in contamination of the optical surfaces.

The present invention permits the use of a simple process for sensor manufacture. No spacers are required to define the beam/fiber spacing and no pressure access channels need to be formed. Further, no spaces to trap dirt or fluids are present.

Manufacturing costs are low and simple to carry out. The sensor element 30 is simply bonded directly onto the optical fiber 44.

The die for the sensor 30 may be very small, and as such is cheap to make. The hole 46 for the fiber may be made by deep reactive ion etching which is only a few hundred microns wide.

The present sensor may be made extremely small and may have a diameter only slightly larger than the tip of an optical fiber.

Although the present application calls for a beam as the resonating member, it is also envisioned that the resonating member may be of a variety of shapes, including a disk, for example.

Thus, there is shown and described a pressure sensor utilizing an optical beam to sense changes in resonant frequencies of optical resonators which modulate the light by physical resonance.

Although other modifications and changes may be suggested by those skilled in the art, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications as reasonably and properly come within the scope of their contribution to the art.

WE CLAIM:

1. A pressure sensor, comprising:

an optical fiber emitting a light beam;

a beam to respond to changes in pressure;

a substrate having a first surface on which said beam is mounted and having a second surface opposite said first surface, said substrate defining an opening which is open from said second surface of said substrate, said optical fiber being mounted in said opening in said substrate to direct said light beam onto said beam; and

a junction in said substrate to receive a portion of said light beam which impinges said beam to drive said beam into vibration.

2. A pressure sensor as claimed in claim 1, further comprising:

a shell on said first surface of said substrate enclosing said beam, said shell having an evacuated interior space.

3. A pressure sensor as claimed in claim 1, wherein said optical fiber is positioned to direct said light beam through said junction prior to impinging said beam.

4. A pressure sensor as claimed in claim 1, wherein said substrate includes a layer of semiconductor on said first surface and a layer of insulator below said layer of semiconductor.

5. A pressure sensor as claimed in claim 1, wherein said beam of light is infra-red light.

6. A method for sensing pressure, comprising the steps of:

directing a beam of light through a junction in a semiconductor substrate and onto a beam;

providing an optical resonant cavity between said junction and said beam to impose a frequency on said beam of light;

vibrating said beam by electrostatic attraction between said junction and said beam;

varying a frequency of vibration by said beam by changes in pressure to effect changes in said beam of light; and

sensing said changes in said beam of light.

7. A method as claimed in claim 6, further comprising the step of:

providing a evacuated chamber within which said beam is mounted, said evacuated chamber having an outer shell defining an optical resonant cavity between said outer shell and said beam.

8. A method of making a pressure sensor, comprising the steps of:

forming a p-n junction on a first surface of a substrate;

forming a microstructure on a substrate over said p-n junction, said microstructure including a shell and a beam within said shell;

evacuating said shell;

forming an opening in a second surface of said substrate; and

positioning an optical fiber in said opening so as to direct a beam of light onto said beam and said p-n junction to thereby charge said p-n junction and drive said beam into vibration;

receiving light reflected from said beam, said light carrying a frequency of an optical resonant cavity formed between said p-n junction and said beam; and

subjecting said shell to pressure to vary said light reflected by said beam.

ABSTRACT OF THE DISCLOSURE

A pressure sensor is formed on a substrate, the surface of the substrate having a p-n junction and a shell with a beam inside the shell over the p-n junction. The beam and the shell and the p-n junction surface form optical Fabry-Pérot cavities. An optical fiber is positioned in a hole formed in the underside of the substrate below the p-n junction. Light from the fiber charges the p-n junction and drives it into vibration mode. Pressure changes change the tension in the diaphram to vary the frequency with changes in pressure, so that pressure can be detected.

Schiff Hardin & Waite

Inventor(s) YOUNGNER

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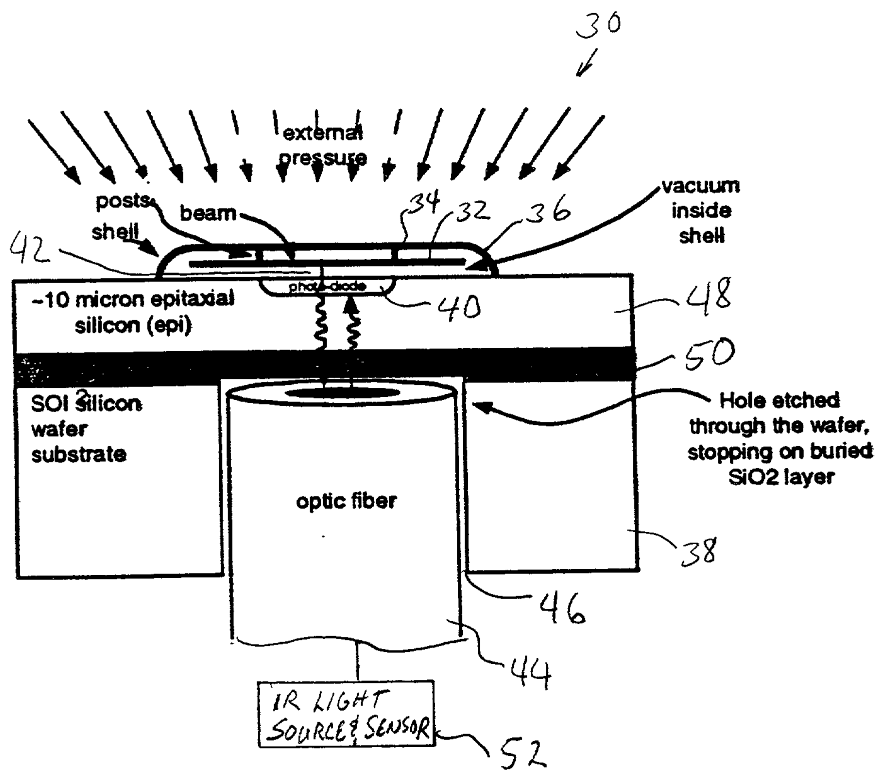

FIG. 1

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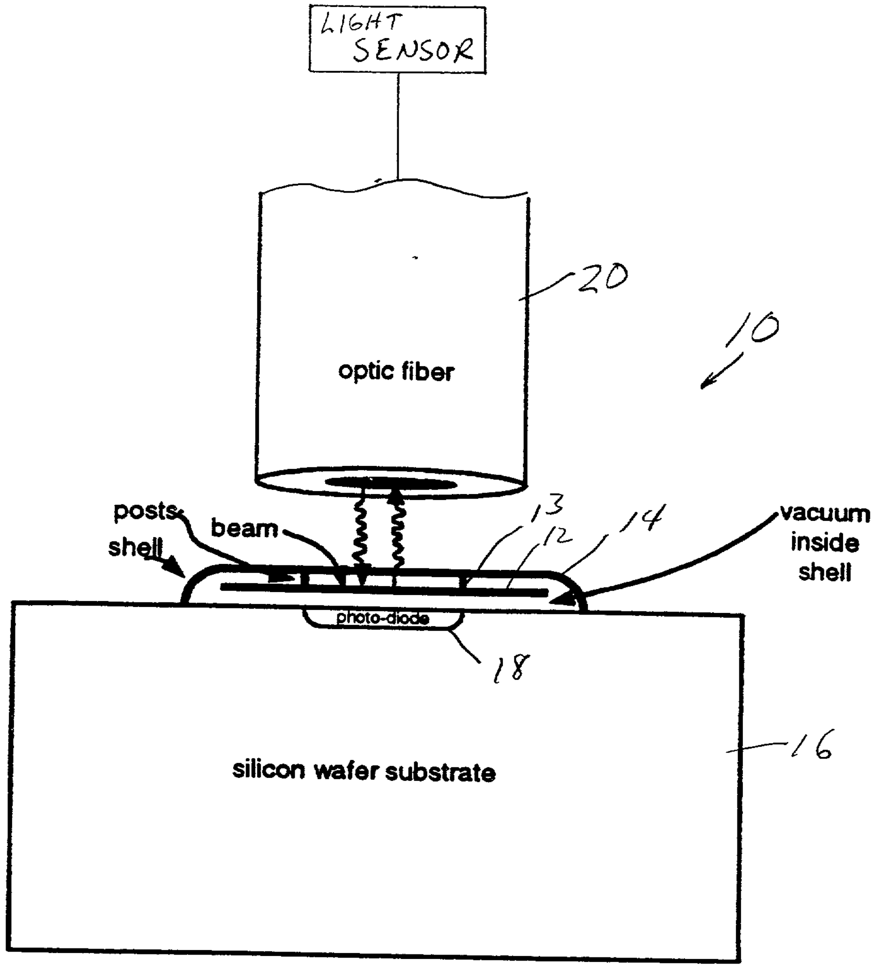
LIGHT SENSOR
20
optic fiber
10
posts
beam
shell
13
12
14
vacuum
inside
shell
photo-diode
18
silicon wafer substrate
16

FIG. 2

Schiff Hardin & Waite

Inventor(s) YOUNGNER

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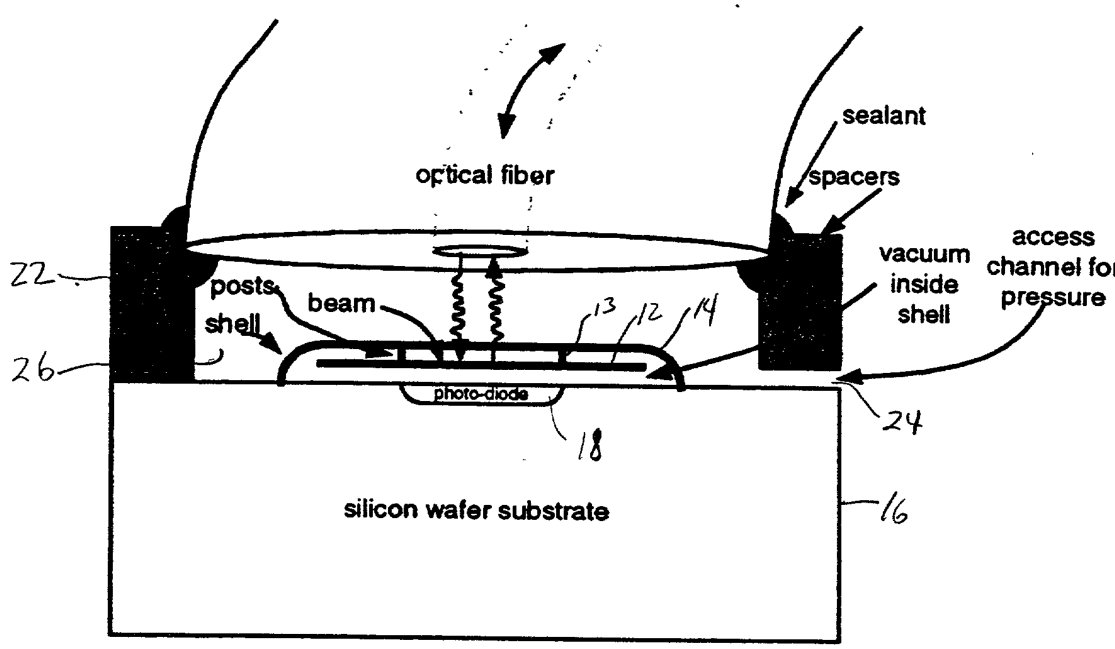

FIG. 3

PATENT

Attorney Docket No.: H0002721

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

OPTICAL PRESSURE SENSOR

The specification of which

(check one)
_X_ is attached hereto
______ was filed on ________________________ as
Application Serial No.________________________
and was amended on ________________________.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).*

I hereby claim foreign priority benefits under Title 35, United States Code §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) **Priority Claimed**

(Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under Title 35, United States Code §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby appoint all attorneys associated with Honeywell Customer No. 000128 and all attorneys associated with Schiff Hardin & Waite Customer No. 26574 to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. Address all telephone calls to Dennis C. Bremer at telephone number (612) 951-6145.

Address all correspondence to Honeywell Customer No. 000128.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of First Inventor Daniel W. Youngner

Inventor's Signature__________

Date__________

Residence__________

Citizenship__________

Full Name of Second Inventor Son Thai Lu

Inventor's Signature__________

Date__________

Residence__________

Citizenship__________

Full Name of Third Inventor __________

Inventor's Signature__________

Date__________

Residence__________

Citizenship__________

*Title 37, Code of Federal Regulations §1.56:

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information

which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) Prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) The closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.